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Bellotti, F., Ott, M., Arnab, S., Berta, R., de Freitas, S., Killi, K. and De Gloria, A. (2011) Designing serious games for education: From pedagogical principles to game mechanisms. In: 5th European Conference on Games Based Learning, 20 - 21 October, Athens, Greece.

http://researchrepository.murdoch.edu.au/28132/

Designing Serious Games for education: from Pedagogical principles to Game Mechanisms

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Abstract: Serious Games represent an important opportunity for improving education thanks to their ability to compel players and to present realistic simulations of real-life situations.
The scientific community is aware that we are just at the beginning of a proper use of gaming technologies for education and training and, in particular, there is a need for scientific and engineering methods for building games not only as more realistic simulations of the physical world, but as means that provide effective learning experiences.
This requires an ever closer cooperation among the various actors involved in the overall SG life-chain, putting pedagogy in a central role, given the educational target of the SGs.
This paper addresses the till-now inadequate integration of educational and game design principles and proposes techniques, methods and mechanisms that allow designers with different background to dialogue among each other and to define games that are able to integrate – by design – entertainment and educational features. In particular, the paper follows a design path that starts from the definition of reference frameworks and then analyses the typical categories of design patterns, before focusing on the user-interaction modalities – seen from a pedagogical point of view – given their relevance for the end-users. In the end, we discuss the sandbox serious game model, that looks suited to implement joint pedagogical and entertainment features.
We believe that the indications provided in this paper can be useful for researchers and stakeholders to understand the typical issues in SG design and to get inspiration about possible solutions that take into account the need to implement tools that are effective both as an entertainment medium and as an education tool.

Keywords/Key Phrases: Serious games, Pedagogical strategies, Game design, Game-based learning, Technology Enhanced learning, virtual worlds, user profiling

1. Introduction

Digital games are widely regarded as high potential educational tools able to provide students with new augmented learning opportunities. According to Kirriemuir and McFarlane (2004) digital games employed in education can be broadly subdivided in two categories: 1) mainstream games, i.e., games that are created solely for fun and 2) learning games, i.e., games that are expressly designed with explicit educational purposes. Games in this last category are also referred to as Educational Games and, with a slightly different “nuance”, Serious Games (SGs) (Breuer and Bente, 2010).
Also mainstream games can be used for education. In this case, the educational value and effectiveness is directly related to the pedagogical choices made by those, typically teachers, who are in charge of carrying out the educational intervention (Bottino et al, 2008).
The focus of this paper, instead, is on games - in particular SGs - ad-hoc designed for educational purposes. The potential of SGs is relevant, because a large and growing population is familiar with playing games, that can present users with realistic and compelling challenges, highly stimulating their information processing capabilities and capturing their concentration span for long duration. “In games, the learning is not only relevant but applied and practiced within that context (Situated

cognition)" (Van Eck, 2006). Menn, (1993) claims that engagement in the job, even if only as a simulation, significantly increases students' knowledge retention.

The SGs' educational potential and actual effectiveness may vary appreciably as a consequence of the pedagogical choices made *a priori* by the game designer (Squire, 2005). Thus, a proper design is key to meet the end-user and stakeholder requirements, that are twofold, on the entertainment and education sides.

Some authors argue that several games have "*per se*" the capacity to elicit and trigger some kind of learning, for instance SGs in the field of reasoning and problem solving skills (Garris et al, 2002). However, it is undeniable that a fine-tuned pedagogy plays a major role in sustaining learning effectiveness.

One of the biggest problems of educational games to date is the inadequate integration of educational and game design principles (e.g. Kiili, 2005; 2007) and this is also due to the fact that digital game designers and educational experts do not usually share a common vocabulary.

This paper stems from the authors' collaboration in the GaLA NoE (Game and Learning Alliance Network of Excellence[1]), in particular in the Technical Committee devoted to Pedagogy. The aim is to analyze and critically discuss the various steps of a pedagogy-driven game design that is rooted in pedagogical principles and is able to go down up to the game mechanisms.

The following sections of the paper explore: "reference frameworks" underpinning and informing SG design (section 2); "game design patterns", intended as means to facilitate the design and development of high quality educational games by providing a shared vocabulary for both instructional and game designers (section 3); user interaction aspects of games which can benefit from the joint effort of pedagogy and game design experts (section 4). As an application case study, section 5 focuses on a particular class of SGs, namely the Sand-Box Serious Games, that, from our experience, looks particularly interesting for implementing effective SGs. Section 6 draws the conclusions and proposes indications for future research.

2. "Reference frameworks" for SGs design

Given the instructional goal, SG research should be strongly grounded in proper educational foundations. "To be effective, serious games must incorporate sound cognitive, learning, and pedagogical principles into their design and structure" (Greitzer et al., 2007). In this regard, it is important to stress that, while serious games are frequently seen as "de facto" instructional, the combination of entertainment and knowledge acquisition is far from being immediate. Games are easily "per se" motivating. However, the next step towards instructional effectiveness is more difficult to accomplish.

Most new generation SGs and Virtual Environments (VEs) adopt a discovery and inquiry-based learning strategy: they are open environments where students should learn basically by exploring contents and solving problems.

This approach, however, is problematic. Although unguided or minimally guided instructional approaches are popular and intuitively appealing, there is evidence from empirical studies that minimally guided instruction is less effective and efficient than instructional approaches that rely on a strong guidance of the student. The advantage of guidance begins to recede only when learners have sufficient knowledge to provide "internal" guidance (Kirschner et al., 2006). The cognitive load theory (CLT) (Sweller, 2008) stresses "instruction [is] based on the facts, laws, principles, and theories that make up a discipline's content" (Kirschner et al., 2006).

Learning is a complex activity that needs several gradual steps, that have to be supported by various tools (e.g., paper and digital, reading and writing, etc.) and generally have to be guided, possibly by an adult person, in order to be useful for the learner and not cause a waste of time/energies or even acquisition of misconceptions or of incomplete/disorganized knowledge. The presence of a reliable adult teacher/educator can help the student to get the meaning of what he is doing, in particular in the first steps. What computer systems (including games) can do is to support teachers - for instance by building an information rich and stimulating environment, providing a wealth of data obtained by tracing the user and making comparisons, favoring personalization and feedback, supporting peer cooperation and dialogue with non-peers. Games can add by themselves a plot and mechanisms that keep the flow (Csikszentmihalyi, 1990) and continuously spur the player to improve.

Awareness of these considerations is limited in the scientific community. And we believe that the proposed perspective provides a major direction to improve current design and consequently favor a

[1] EU Network funded Under FP7

real and useful uptake of SGs as an educational tool, not as a technology pull or a simple pedagogical fashion.

One of the keywords of current SGs and VEs is “experience”, according to Kolb’s (1984) definition of learning as “the process whereby knowledge is created through the transformation of experience”.

In Kolb’s experiential model of learning, individuals are encouraged to reflect on the actions and consequences, so to foster understanding and reapplying this understanding to future actions. Kolb defines four possible learning styles: (i) Divergent (feel and watch), (ii) Assimilative (watch and think), (iii) Convergent (do and think) and (iv) Accommodative (do and feel). These Kolb’s styles are possibly interrelated depending on individual preferences, and may result in four different outcomes: Concrete Experience (feel), Reflective Observation (watch), Abstract Conceptualization (think) and Active Experimentation (do).

A similar cataloguing of learning styles has been proposed by (Fleming and Mills, 1992), that developed a theory – VARK - that categorizes learners: Visual learners (with a preference for tools such as pictures, concept maps), Aural learners (listening and discussion), Reading/Writing-preference learners(textual stimulus), and Kinesthetic or Tactile learners (movement and hands-on practice).

Kolb’s experiential learning model has been recently revisited in order to include new generation VEs and SGs. To conceptually support issues of game design using pedagogically driven approaches, the Four Dimensional Framework (4DF) (de Freitas & Oliver, 2006) and the SG Exploratory Learning Model (ELM) (de Freitas & Neumann, 2009) have been proposed. These models open the capability for learning through the experience of exploring SG/VE spaces.

4DF suggests to inform game design by referring to four dimensions, such as: learner profiling (e.g. ICT skills, gaming experience), selection of pedagogies used (e.g. associative, cognitive or situative), used representation (e.g. level of fidelity, interactivity and immersion) and context within which learning takes place (e.g. disciplinary context, place of learning). By following the four dimensions model, game developers should be able to design SGs by taking into account the learning characteristics of learners and the different pedagogical and contextual constraints so to enact effective absorption, promote reflection on knowledge and transfer these learning variables into real-world scenarios.

Similarly, the ELM model extends from Kolb's experiential learning model to include the typical and popular characteristics of VEs and SGs, such as the 3D world settings and the social interactive learning aspects.

In ELM, learning sequences and experiences are so to say “choreographed”, to support peer interactions and exchanges. This is made possible also thanks to the strong support of the user’s kinesthetic experience. For instance, Arnab et al (2011) explored the use of tactile interactions in a game-based learning environment implemented atop of a multimodal browser-based platform aimed at promoting “hands-on” engagement with a topic - the cultural heritage, in the implemented case.

The models put an emphasis on sequencing learning experiences, meta-reflection, peer assessment and group work, that are interesting and innovative aspects of SGs. However, it is important to stress that this must not hinder the importance of student guidance and of the curriculum. This does not intend to neglect the fun aspect, but to stress the educational effectiveness of a game for its users.

In this sense, it is important to highlight that SGs, rather than an “all comprehensive” teaching tool, look particularly suited as an instrument for motivating beginners to new topics and as a practicing tool to apply and test knowledge acquisition (Bellotti et al., 2010). This consideration should help designers to optimize the efforts and the expected results.

3. “Game design patterns” as a shared vocabulary and common viewpoint for SG designers

After adoption of a reference framework for design, a subsequent step is given by the necessity for designers to share a vocabulary for design analysis, documentation and communication.

This need is stringent in SG design, because of the apparent difficulties in mastering a complex relational web including education, psychology, technology, art, business, and creativity. Practical design tools are necessary in order to effectively implement educational aspects in the designs. A major conceptual tool, in this direction, is the definition of pedagogically informed game design patterns (Alexander, 1977). It is important to note that the term design pattern is concerned with content, in our case, rather than with programming (Gamma et al., 1994).

Porting the design pattern concept into the educational games field, Kiili (2010) has identified a number of patterns, for which he proposed six categories addressing crucial educational aspects that game designers should take into account when designing educational games.

- *Integration patterns* describe solutions that harmoniously integrate game elements and learning objectives in pedagogically meaningful ways. The integration of learning objectives and gameplay creates the foundation of a game and usually arouses constraints that affect the whole design.
- *Cognition patterns* describe solutions that trigger reflective and metacognitive processes in players and stimulate players to process relevant content experienced through gameplay. Ketamo and Kiili (2010) emphasize the meaning of cognitive feedback in educational games. The aim of cognitive feedback is to grasp player's attention, focus it on essential learning content and stimulate player to reflect on his or her experiences and tested solutions in order to further develop his mental models, validation of hypothesis and formation of new playing strategies. The results have indicated that the sooner the player notices the cognitive feedback and grasps it meaning, the more effectively can he play the game.
- *Presentation patterns* aim to ensure that the player's processing of the content is effective. Learners are challenged to extract relevant information from a game world, select corresponding parts of information and integrate all such elements in a coherent representation. This is demanding, because the game world may change while playing, important information may be presented only a while, and thus it needs to be kept active in working memory in order to allow integration of information. This may impose an excessively high cognitive load and hinder learning. Thus, game designers should consider the cognitive price of every element and that visual effects should be used to highlight the crucial elements. It is not enough that players can cope with challenges, but they need to process game content so to learn. Test results have indicated that players' perception patterns tend to vary a lot and players miss relevant information during playing.
- *Social interaction and teaching patterns* are interwoven into cognition patterns. They describe solutions that facilitate learning or teaching (trigger reflective and metacognitive processes) through social activities and socially constructed game elements. This pattern category is not restricted to direct game activities, but can also include patterns that guide debriefing sessions, for example. In particular, teaching patterns describe solutions that facilitate teacher's work by providing observation, assessment and participation possibilities. Games could be armed with effective tools that provide diagnostics and summarizations of learners' gaming behavior. Such tools could help teachers to concentrate on learners' most crucial problems and master relatively large learner groups with numerous variances in skills. Pedagogical support to teachers may be one of the key points for spreading SGs.
- Finally, *engagement patterns* provide a means of wrapping the whole gaming experience into a meaningful and motivating package. They describe solutions that motivate players to perform better in a game, facilitate learning and increase playing time.

In general, SGs design patterns draw from the well established knowledge of game design patterns (Bjork and Holopainen, 2005), and add a second foundation beside entertainment: pedagogy. In our experience, pedagogically-informed game patterns represent a key practical tool to support the necessary collaboration among experts - mainly computer programming, pedagogy and the specific target domain – in all the choices to be done when designing a SG.

In the next section we focus in particular on presentation patterns, given their importance from the point of view of the end-user.

4. Focus on presentation and user interaction

As seen in the previous sections, there is a wide consensus that pedagogical choices made *a priori* and embedded in the pedagogical design of games may contribute to enhance learning effectiveness (Kiili, 2007). Such pedagogical choices may affect, to a different extent, different aspects and parts of a game.

The first basic choice concerns the definition of the target users and the elicitation of their needs. Consequently, the content to insert in the game is to be decided. Besides guaranteeing the correctness and suitability for the target age and for the intended learning purposes, a number of other pedagogical aspects are to be considered, in particular the flow/harmonization of the content presentation, also considering the need to graduate the levels of difficulty.

In this section we shortly focus on design items and choices related to the content presentation, given their relevance for the final product.

- *Interface* - Interface appeal is key because games, by definition, have to be engaging to play, and also because a nice graphic aspect can attract demographics that are traditionally averse to instructional activities. This is often neglected when designing SGs, for which designers tend to think of their users as a captive audience. But this assumption strongly limits the potential of the final SG. In interface design, however, beside the pure graphical attractiveness, there are also other aspects that should be designed considering also the pedagogical point of view. These include the identification of relevant/irrelevant functionalities/modules - to be appropriately displayed in place and time according to their salience - and the appropriate use of audio to substantiate and foster comprehension and learning. Fig. 1 shows two different interfaces chosen for the same simple casual game (Hanoi Towers), from which it appears the difference in overall clearness and potential ability to help focus on relevant elements of the game.

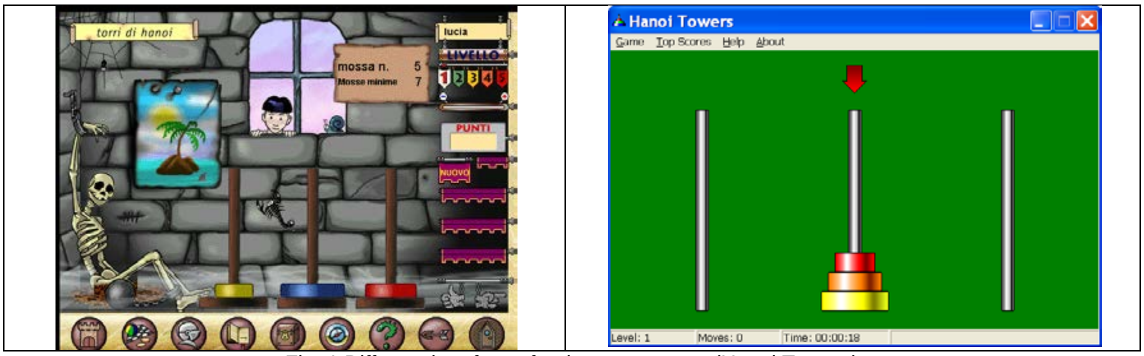

Fig. 1 Different interfaces for the same game (Hanoi Towers)

- *Method/level of interaction* – The interaction modalities for a game have to be decided coherently with the application's educational strategy (e.g., a question-answering or an inquiry/exploratory strategy), which in turn is to be determined by the game's inspiring pedagogical principles. As a consequence, also the level of interaction should be different. For instance, "Question & Answer" environments typically require a paced and homogeneous user-computer interaction, while open environments, like simulations or adventure games, where inquiry or discovery learning strategies are adopted, are per se fully interactive and, at a further level, additional interaction (e.g. request of specific hints/explanations) should happen mainly "on demand", when the need emerges.
- *Feedback and reward* - The type of feedback provided by the system as a consequence of user actions (from simple yes/no answers to full re-explanation and adapted, customized feedback to the user's responses) is a key point for all types of digital educational products (Timmers and Veldkamp, 2011). Fig. 2 shows the contextualized feedback of a classic battleship puzzle game, Hexip, where instead of showing the solution or simply highlighting the user mistakes, the system shows the right way to follow, suggesting reflections and specific considerations on the actual game situation.

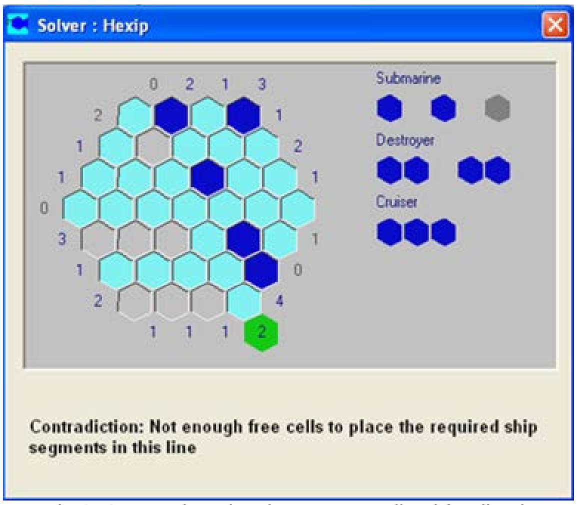

Fig.2. Screenshot showing contextualized feedback

The reward provided to the user in case of positive achievements is an important design element,

since it could offer a strong performance motivation. It has to be perceived as a reward for the work done, but should also be effective for stimulating further gaming and learning.
In general, feedback should be strictly linked with the needs of the target end-users and coherent with the overall learning objectives and adopted educational strategy.

- *Type of evaluation of performance and level of metacognitive support provided* - The capacity of the digital tool to provide users with a proper evaluation of their performance is a key aspect to support and enhance the SG effectiveness and impact. The need for precise pedagogical assessment is necessary in both the typical evaluation methods: summative (final assessment of the overall performance) and formative *(in itinere,* aimed at supporting reflection on and adjustment of learning behavior). This is expected to guarantee that users are fully aware of their successes/failures, so that they are in a better position to improve their performance. Embedding formative and/or summative evaluation elements in the game has different pedagogical implications closely related to the level of performance awareness which, in turn, has clear implications on metacognition and metacognitive aspects of learning behavior (Abbott et al., 2009; Roll et al., 2007). Also, inserting assessment in games should not obstacle the overall flow and should be smoothly embedded into the actual game mechanisms. This is not easy, and the literature presents some good practice cases, mot a coherent theory or model (e.g., Swarz et al., 2010 and Zielke et al., 2009).

5. From theory to practice: the SandBox SG model

The virtual world (VW) in which a game is set can provide itself an important value for instruction. Actually, several effective SandBox Serious Games (SBSG) – they also have a counterpart in successful entertainment games, such as Grand Theft Auto and Oblivion (Squire, 2008) - have an organization that tends to support players in building a suited knowledge structure for the addressed topic(s) (Qin et al., 2010). In rough terms, the model consists of: (1) a spatial organization - the VW - where knowledge is distributed (e.g., Sliney and Murphy, 2008) and that induces spatial information processing and provides landmarks to support orientation (Slater et al., 2009); (2) contextualized tasks, that are spread and contextualized in the VW. Tasks embody units of knowledge that can be discovered by the player. The Task Based Learning (TBL) theory (Willis, 1996) stresses the importance of concrete, focused activities to construct knowledge and develop skills.
A player explores the environment accomplishing missions involving a sequence of small tasks, each of which has a specific, limited instructional target. Pedagogical usefulness of this approach has been argued in (Frazer, 2007), presenting the MyLA (My Learning Assistant) experience, highlighting the importance of stimulating learners through questions and timely, accurate, context-sensitive, answers.
The missions' complexity, given by the difficulty of the tasks and of the environment to be explored, can grow up gradually towards ever more complex objectives,.
Tasks may be instances of templates (e.g. various sorts of minigames with different contents), with the advantage that interaction modalities can be re-employed by the player in several contexts, keeping the cognitive load low, which is good for the Cognitive Load Theory (CLT). Moreover, development of tasks can be efficiently supported by an authoring toolkit, allowing teachers, and even students, to develop/customize content (Bellotti et al., 2010).
Availability of a large database of semantically annotated tasks leads to the possibility of a dynamic scheduling of tasks. Bellotti et al., (2009a) present an Experience Engine (EE), that exploits computational intelligence to schedule tasks matching the needs estimated by profiling the user performance and with the aim of keeping the learners in the proper Zone of Proximal Development (ZPD) (Vygotsky, 1976) and enforcing a teacher-defined pedagogical strategy. This system, again, is able to provide a level of guidance that should help the learner to make the most of his exploration without getting lost in a potentially wide knowledge space.
In the proposed approach, a game does not need a detailed story specification. There is a high-level challenge (e.g., a treasure hunt), that spurs players to competition/cooperation through explorations of a VW. This simple narrative structure would cause a minor cognitive load to the player, leaving more space for knowledge acquisition.
Tasks may be of different type, also supporting different learning styles (e.g., the Kolb's and VARK styles, in Bellotti et al., 2009a), that could be stressed in the gameplay either to improve the learner's skills or to make the learning easier by exploiting his most favorite skills - depending on the teacher strategy. In fact, the methodology allows the teacher to specify the requirements for a runtime scheduling policy that maximizes learning objectives. The policy is learnt by the EE, which is the responsible for the final scheduling of the task. The policy allows the teacher to define several

educational targets, among which the expected difficulty curve and tasks' overall learning style distribution (Bellotti et al., 2009b).The SBSG-EE model has been implemented in SGs for the cultural heritage and maritime education domains, but it is clearly domain-independent (Bellotti et al., 2009a).

6. Conclusions and future work

SGs represent an important opportunity for improving education, also in a life-long learning perspective, thanks to their ability to compel players and present realistic simulations.
Beside this, there is the awareness that we are just at the beginning of a proper use of gaming technologies for education and training (Johnson, 2005) and there is a need for scientific methods for building games as means that provide effective learning experiences (Greitzer et al., 2007).
This requires a closer cooperation among the various actors involved in the overall SG life-chain (students, teachers, educators, developers, companies, etc.).
This paper addresses the till-now inadequate integration of educational and game design principles and proposes methods and mechanisms that allow designers with different background to dialogue among each other and to define games that are able to integrate – by design – entertainment and educational features.
We believe that the indications provided in this paper can be useful for researchers and stakeholders to understand the typical issues in SG design and get inspiration about SGs that are effective both as entertainment media and as education tools.
The next steps of our research work concerns an improvement of the presented models/techniques (i.e., reference frameworks, design patterns, interaction modalities and sandbox serious game model). In the same time, these or similar techniques may be assessed and enhanced also by other experts and researchers, in order to achieve the long-term aim of defining proper rules and models for an effective design of SGs.

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